N68 11103

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Ammonia-Water Atmosphere Storage
Case 710

DATE: November 27, 1968

FROM: R. Gorman

ABSTRACT

The use of NH_3 and H_2O as storable forms of O_2 and N_2 is shown to integrate well with the Sabatier reactor and electrolysis cell oxygen recovery system. Elimination of cryogenic storage, substantial weight savings, and decreased leak loss sensitivity are achieved through this method of storage.

The use of NH_3 as an N_2 storage form also enables one to approach the performance of a Bosch reactor and electrolysis cell system with the Sabatier system. The Sabatier system is at present considered to be within the state-of-the-art while the Bosch system has not yet achieved reliable operation. The NH_3-H_2O storage used in conjunction with the Sabatier reactor and electrolysis cell has all of the advantages and few of the disadvantages of either major system.

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MEMORANDUM FOR FILE

INTRODUCTION

The two CO_2 reduction systems which are being considered for use in regenerative life support systems are the Bosch and Sabatier reactor systems. The choice which confronts systems designers is whether the developmental difficulties which have plagued the Bosch reactor system are worth the performance advantage it offers over the reliable Sabatier reactor system.

Much of the Bosch system performance can be achieved with the Sabatier reactor by storing leakage makeup oxygen and nitrogen as water and ammonia. In addition, there are significant advantages accruing from the non-cryogenic logistics resupply and space storage of the oxygen and nitrogen as ammonia and water. A detailed analysis and description of oxygen and nitrogen systems appear in the Appendix. A brief summary of the systems and results follows.

System Descriptions

Previous Sabatier reactor systems have used H_2O storage as a way of supplying hydrogen and oxygen. Figure 1 shows a schematic of the Sabatier system with water storage and cryogenic nitrogen storage. If enough water is electrolyzed to supply hydrogen to reduce all the CO_2, there will be more than enough oxygen to supply the crews metabolic needs. Therefore the mode of operation is to only produce enough oxygen as is needed, and to dump the unreacted CO_2. If there is leakage, more oxygen will be required and Figure 2 shows the daily total (including tankage) H_2O and LN_2 consumption with varying leak rates for one man. At the relatively high leak rate of 2.38 lb/man day (for a 50:50 N_2O_2 atmosphere), all of the CO_2 is being reduced.

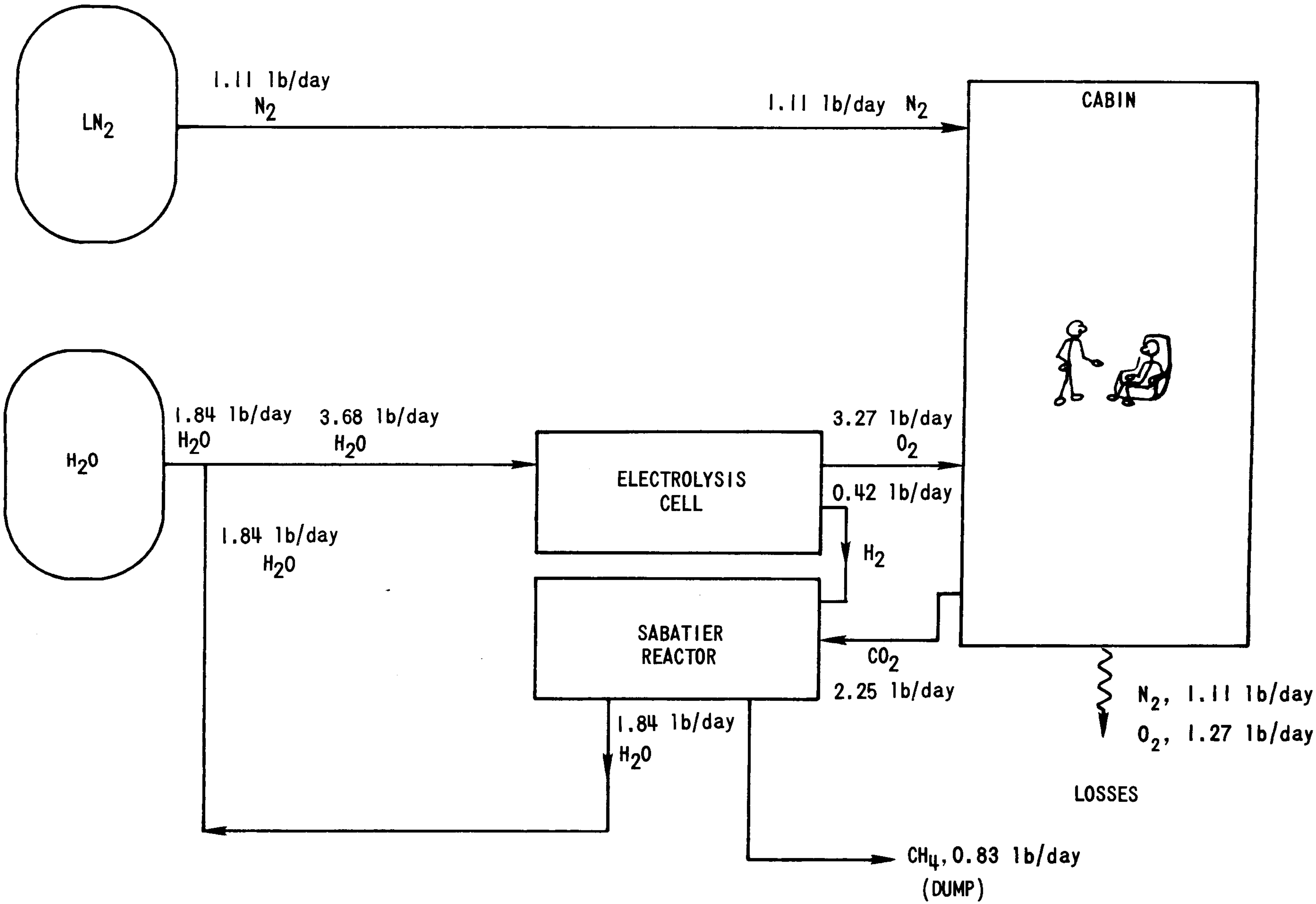

FIGURE 1. SABATIER REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR 2.38 lb/day LOSSES _ ONE MAN

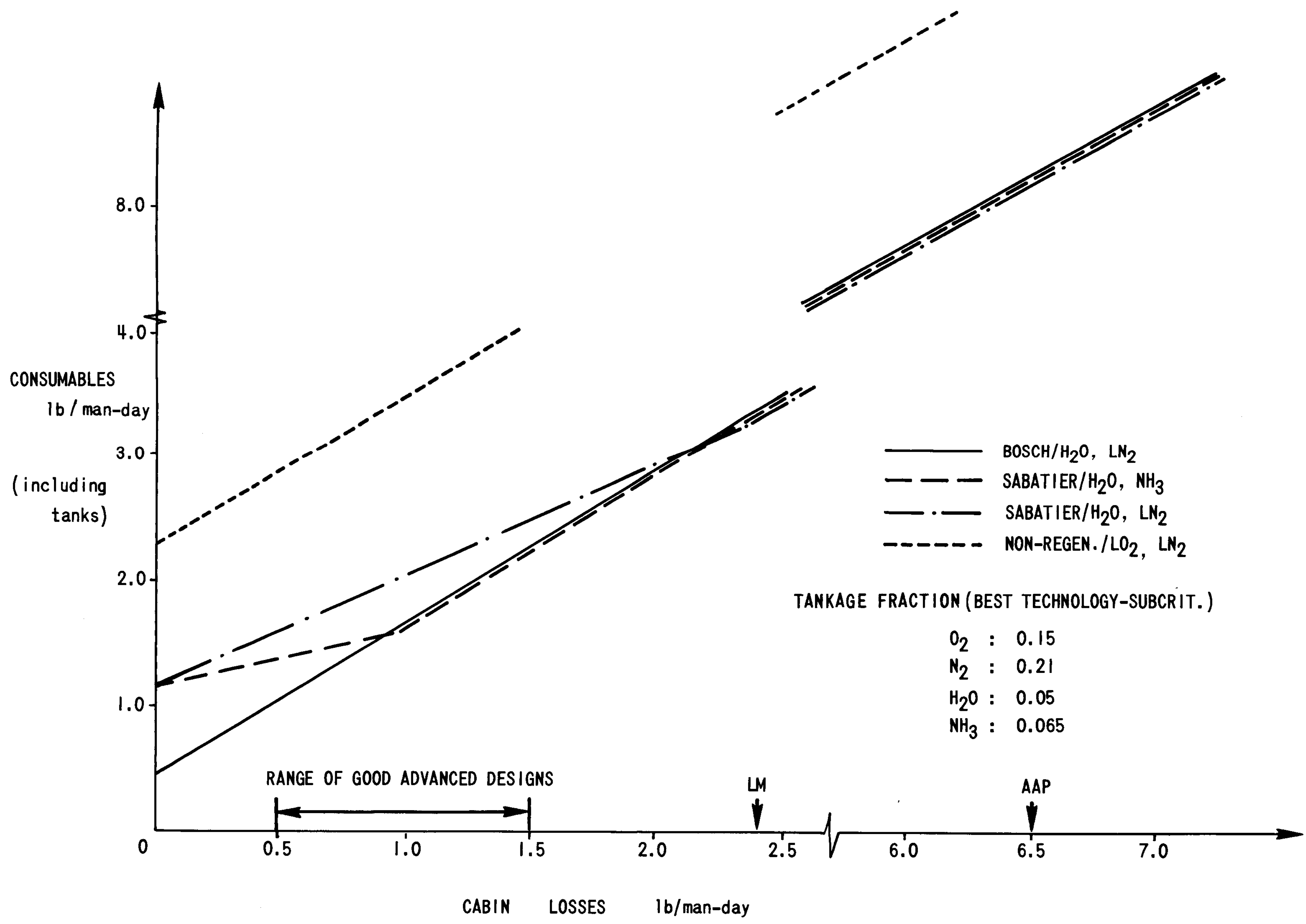

FIGURE 2 DAILY CONSUMABLES FOR ONE MAN VERSUS LOSS RATE

The Bosch reactor as shown in Figure 3 has a much lower storable consumption because it reduces all of the CO_2 without a hydrogen requirement. The total daily storable weight of H_2O and LN_2 is also shown on Figure 2 versus leak rate.

The NH_3-H_2O combined hydrogen, oxygen and nitrogen storage mode when combined with the Sabatier reactor is shown in Figure 4. The only component of the NH_3-H_2O system which is different from the other systems is the NH_3 dissociator-separator. While such units have not been used before in spacecraft, they have been used in the chemical industry for more than 10 years. The power consumption is very low and is purely thermal so that it may be supplied by a radioisotope heat source.

The use of NH_3 as an additional hydrogen source results in complete CO_2 reduction at a leak rate of 0.955 lb/man day. Figure 2 shows the total weight of NH_3 and H_2O (including storage tankage) versus leak rate.

System Performance

The total atmosphere system weight (MOL sieve, reactors, NH_3 dissociator, and electrolysis cell and total storage) for an 803 day mission is shown in Figure 5, versus leakage rate. The Bosch reactor system is the lowest weight at the lowest leak rates, however, the use of NH_3 as an N_2 storage mode enables one to approach or equal the performance of the Bosch reactor at the low leak rates which could be expected of advanced spacecraft systems. In addition, the non-cryogenic nature of the storable is a significant operational safety and design advantage. Because the tanks are non-cryogenic, there is no penalty involved in making many small tanks rather than one large one. The tankage weight for H_2O and NH_3 is so much less than that for even the best cryogen tanks that the tankage weight per pound of N_2, and O_2 is approximately the same for either form. The spacecraft can be left in orbit in the dormant condition without the problem of O_2 and N_2 boiloff losses, and current NASA guidelines call for a 6 month dormant orbital storage period. Orbital resupply of NH_3 and H_2O can be accomplished without the inefficient transfer line boiloff losses expected with cryogenic N_2 and O_2 with less pad complexity and orbital operations hazards. Finally the hazards associated with storage of LO_2 and LN_2 due to meteoroid punctures or tank failure are reduced by H_2O and NH_3 storage.

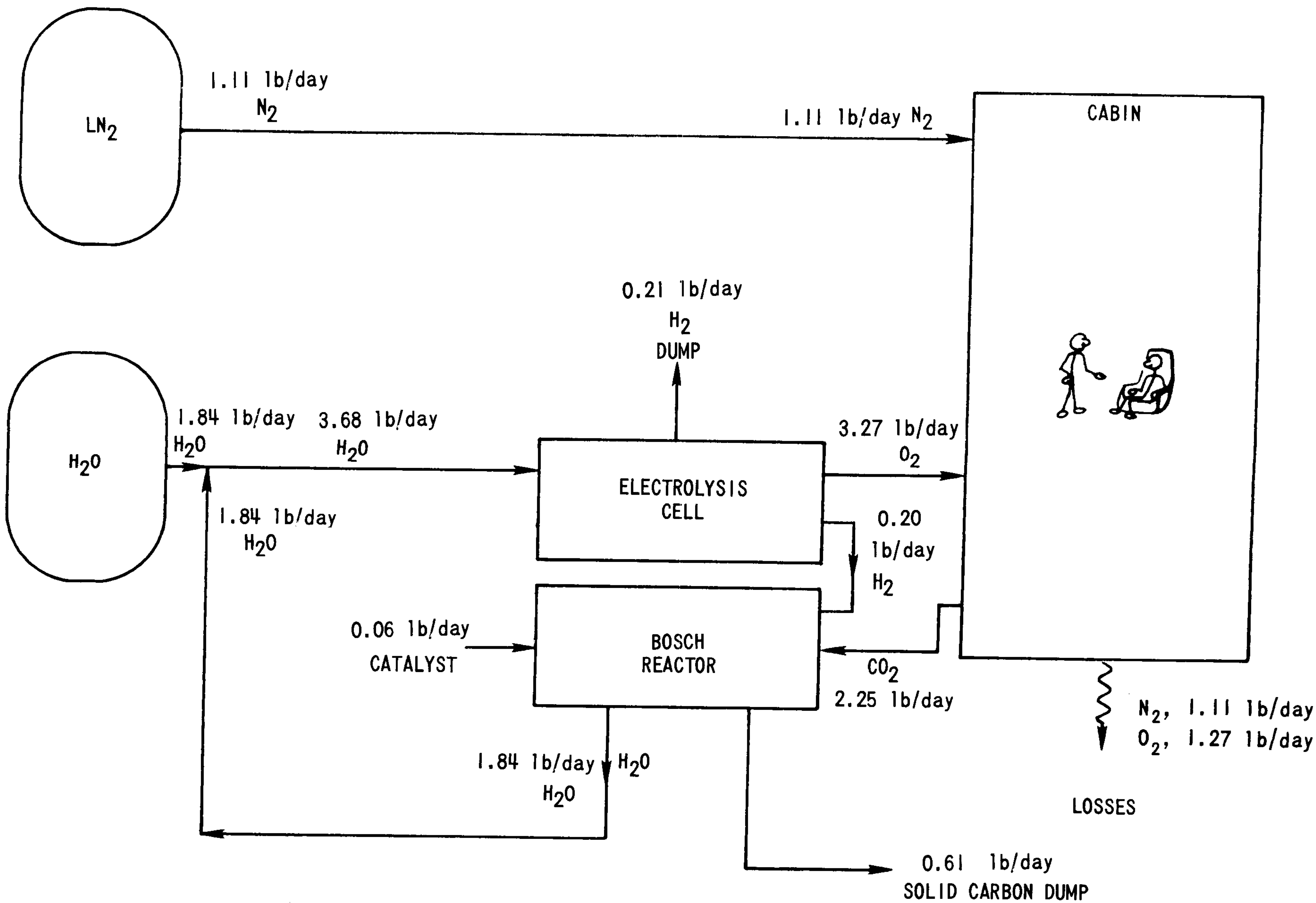

FIGURE 31. BOSCH REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR LOSS RATE = 2.38 lb/day - <u>ONE MAN</u>

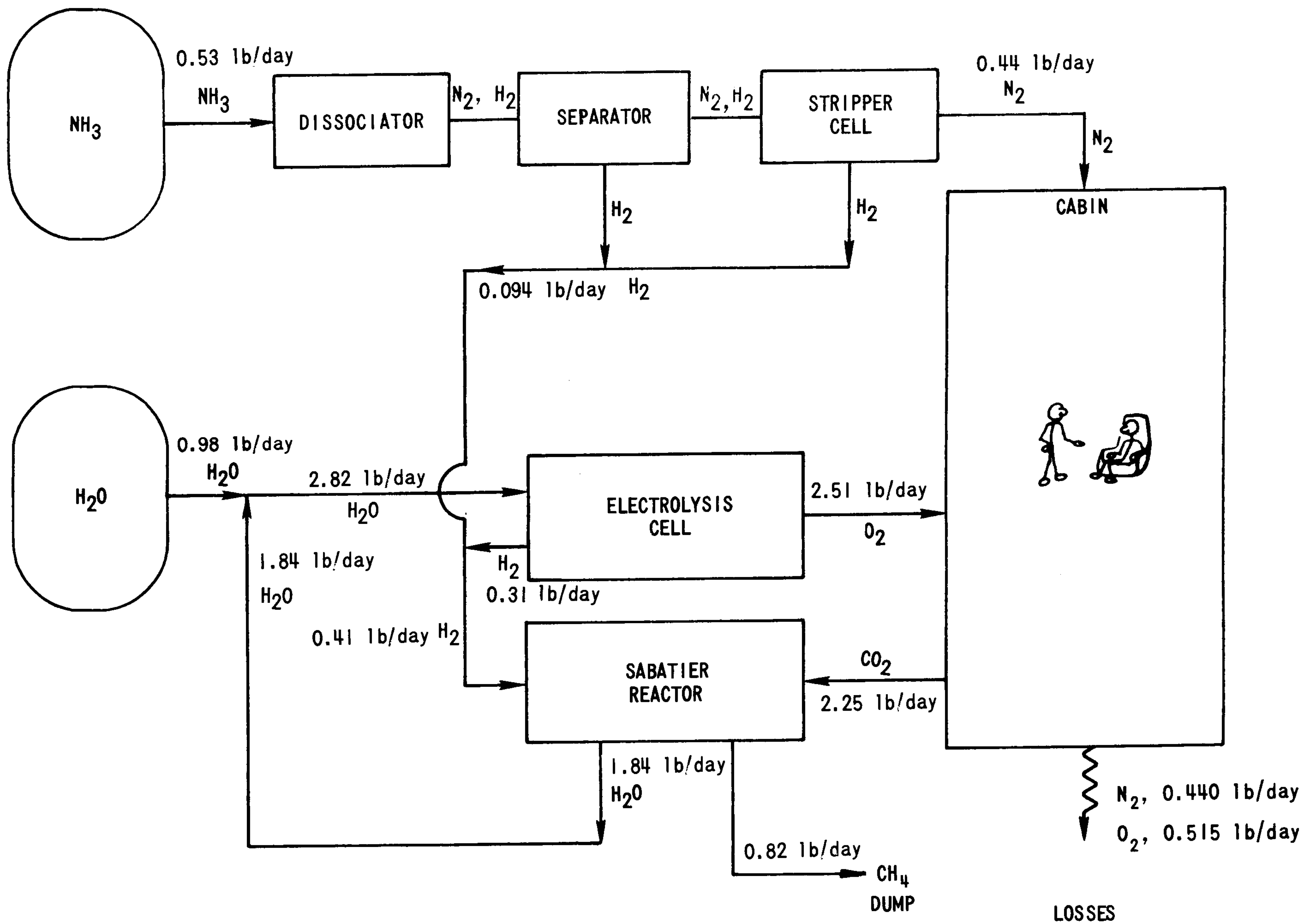

FIGURE 4. SABATIER SYSTEM WITH H_2O/NH_3 STORAGE
LOSS RATE OF 0.955 lb/day FOR ONE MAN

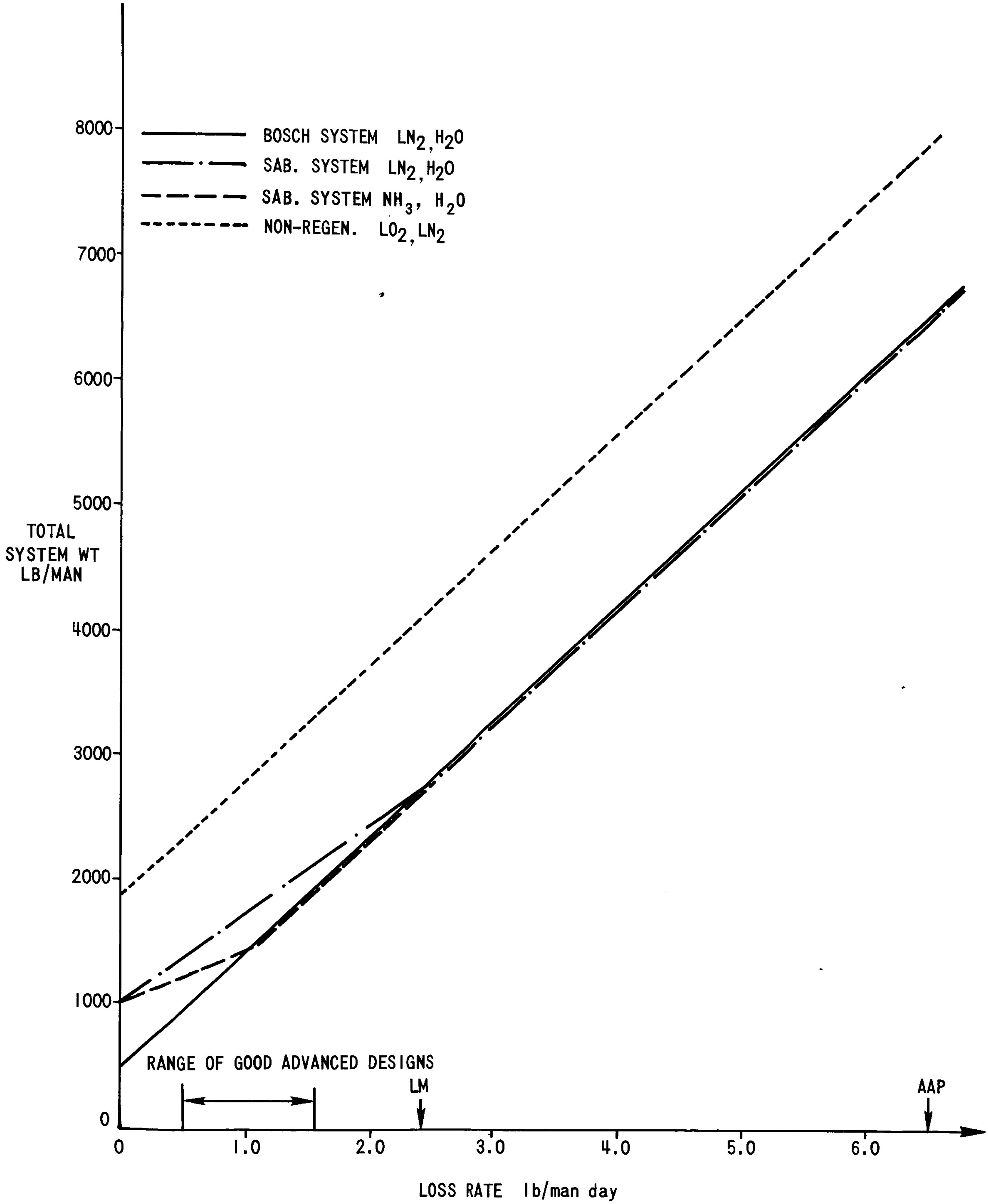

FIGURE 5 SYSTEM WEIGHT FOR ONE MAN VERSUS LEAKAGE RATE FOR 803 DAYS (2 years + 10%)

CONCLUSION

The NH_3-H_2O Sabatier reactor system offers a system with highly desirable performance, development and operational features. It is recommended that NASA conduct a more detailed systems analysis including evaluation in laboratory simulations.

1012-RG-sjh

R. Gorman

Attachments

APPENDIX

1.0 INTRODUCTION

For long term missions the daily requirements for the cabin atmosphere add up to a substantial portion of the spacecraft weight. Although some stores will always be required for cabin leaks the supplies can be largely reduced by regenerating the oxygen consumed by the crew from the crews respired CO_2 and H_2O.

This regenerative approach introduces a need to store 3 different expendables:

- oxygen for breathing and cabin leaks,
- nitrogen for cabin leaks, and
- hydrogen to support the chemical reaction used to reclaim O_2 from CO_2.

This suggests combining the H_2, N_2, and O_2 storage requirements as storage of NH_3 and H_2O--both non-cryogenic liquids. This memorandum will discuss O_2 recovery systems, comparing cryogenic and H_2O/NH_3 storage systems. The major hardware items and their availability will be defined.

2.0 OXYGEN RECOVERY

Man's metabolic processes convert O_2 and food into CO_2 and H_2O. Typical metabolic rates are:

- 2.0 lb/day O_2 consumption per man,
- 1.4 lb/day food consumption (dry weight) per man,
- 2.25 lb/day CO_2 production per man,
- 0.5 lb/day H_2O net, recoverable from respired air and urine per man.

Appendix (continued)

In the CO_2 reduction processes, the CO_2 is reduced with H_2 to give H_2O. The resultant H_2O is electrolyzed to give H_2 and O_2. One CO_2 reduction process, the Bosch process, reduces the CO_2 to water and carbon by reacting it with H_2. Its reaction is:

$$\text{energy} + CO_2 + 2H_2 \xrightarrow[1800°F]{\text{Iron Catalyst}} 2H_2O + C$$

The H_2O is then electrolyzed to H_2 and O_2, the O_2 is directed to the cabin and the H_2 is directed back to the Bosch reactor. The Bosch reactor, because it reduces the CO_2 to carbon, must then get rid of the carbon which would otherwise accumulate in the reactor. Experience so far with the Bosch reactor (Reference 1) has shown that the reacting stream depositions carbon on nearly every interior metal surface. This deposit is hard and not readily removable. It also partially dissolves the iron upon which it deposits. The problem of controlling the carbon deposition has caused interest to shift largely to the Sabatier process.

The Sabatier process reacts the hydrogen with the CO_2, producing methane and water. The reaction is:

$$4H_2 + CO_2 \xrightarrow[\text{Pd Catalyst}]{500°F} 2H_2O + CH_4 + \text{energy}$$

The water is then condensed out of the reactor exhaust stream and the remaining CH_4 discarded. The condensed water is then electrolyzed as in the Bosch process. This system requires an external supply of 1 lb of H_2 for every 8 lb of O_2 recovered from CO_2 due to the loss of H_2 with the CH_4.

Sabatier reactors have shown good performance and reliability in life support simulator tests (Ref. 2, 3, 4) at LaRC, Lockheed, and Douglas. The lower reaction temperature and lack of power requirement also make the Sabatier reactor attractive to the life support system designer.

3.0 CABIN LOSSES

Loss rates to be expected from leakage have been estimated to be anywhere from 0.5 to 6.5 lb/man day depending on the person doing the estimating and the level of techology assumed. Barring leaks, however, there will still be a loss of cabin atmosphere due to airlock operations, cabin purges, and unintended cabin depressurization (meteors, fires, ECS malfunction).

Toxic contaminants, released in the spacecraft by metabolic activity, oxidation of materials, material outgassing and operations of the water management system, may not all be destroyed or eliminated in the toxin burner (catalytic oxidizer) and charcoal absorbant beds. It may be prudent to periodically purge the cabin to vacuum and let it "vacuum soak" for a few hours to eliminate the micro-contaminants which have built up. A fire, no matter how small, will probably release large quantities of toxic substances which can only be eliminated by purging the cabin to vacuum and "soaking" it. If the cabin contains 1000 ft^3 per man and is purged every 90 days a loss rate of 0.45 lb/man day (of 7 psi N_2 - O_2) results. A 200 ft^3 airlock would expend 5 lbs of atmosphere if no scavenging pump were used.

4.0 CONSUMABLE STORAGE

Even with total O_2 recovery from metabolic waste products the losses overboard from the cabin require storage of significant quantities of O_2. A non-cryogenic approach to this problem is to store this O_2 as H_2O and produce the O_2 using the available electrolysis cell. This will avoid the problems involved in cryogenic O_2 storage at the expense of increased electrical power consumption and load on the electrolysis cell. The excess H_2 in the H_2O can then be used in the Sabatier reactor. The amount of H_2 in the H_2O, required for leakage O_2 makeup, is usually not enough for the Sabatier reactor to reduce all of the CO_2. In this situation there are several ways of operating the O_2 recovery system. They are:

- Supply the needed H_2 from H_2 storage (gas or liquid).
- Operate with partial CO_2 reduction.

Appendix (continued)

- Use NH_3 storage as a combined source of N_2 and H_2.

All of the O_2 in the CO_2 can be recovered if sufficient H_2 is stored. The total weight of H_2 stored is relatively small, less than 1/8 of the weight of the O_2 recovered, but long term storage is difficult. The relatively small amounts of H_2 needed result in small tanks with large area-to-volume ratios which increase the thermal insulation requirements for the tank walls. The resultant H_2 tank weight is larger than the weight of a tank of H_2O containing an equivalent amount of H_2. Thus when tank weights are included, hydrogen is stored more efficiently as water than it is as liquid hydrogen.

The H_2O used for H_2 storage also contains O_2 which reduces the requirement for reducing CO_2. The uses of H_2O as a combined H_2O and O_2 storage does not supply enough H_2 to completely reduce the CO_2. The resultant ecology therefore results in dumping of some CO_2.

N_2 is somewhat more difficult to store as a cryogenic liquid than O_2 but not to the same degree as H_2. LN_2 has a lower heat of vaporization and density than LO_2 and this requires larger better-insulated tanks in order to hold the same quantity of cryogen. A way to avoid the cryogenic problem is to store N_2 in the form of NH_3. The NH_3 is a subcritical liquid at room temperature and low pressure (150 psia) The NH_3, in addition contains H_2, which will enable us to reduce more CO_2 and decrease the H_2O requirement.

Two possible approaches with the Sabatier reactor CO_2 reduction system are:

1. H_2O and NH_3 storage.
2. H_2O and LN_2 storage.

Appendix (continued)

4.1 Tankage Weight

H_2O can be stored in minimum gage tankage of any convenient shape because it is a room temperature liquid at low pressure. Estimated H_2O tank weight fraction is 0.05. NH_3 is a liquid at room temperature and 150 psi. This low pressure results in a tankage weight fraction estimated at 0.065. The mode of NH_3 use (in a high temperature dissociator) eliminates the need for any phase separation.

Cryogenic liquid storage of LO_2 and LN_2 in advanced tankage systems (subcritical tanks, dacron tank supports) is possible for two years at a weight fraction of 0.15 for LO_2 and 0.21 for LN_2 (LN_2 has a lower density, boiling point than LO_2).

5.0 ATMOSPHERIC SUPPLY SYSTEMS

The atmospheric supply system is the combination of the O_2 recovery system and the stored expendables. Four systems will be considered:

1. Sabatier reactor system with LN_2 (cryogenic) storage of N_2 and H_2O storage of O_2, H_2.

2. Sabatier reactor system with NH_3 storage of N_2, H_2 and H_2O storage of H_2, O_2.

3. Bosch reactor system with cryogenic storage of LN_2 and H_2O.

4. No CO_2 reduction with cryogenic storage of LN_2, LO_2.

6.0 SYSTEM 1 DESCRIPTION (SABATIER/LN_2/H_2O)

Figure 1 shows a system schematic representation of the interactions of a LN_2/H_2O storage Sabatier reactor atmospheric supply system. The system is composed of:

- A CO_2 separator system which removes the CO_2 from the cabin atmosphere.

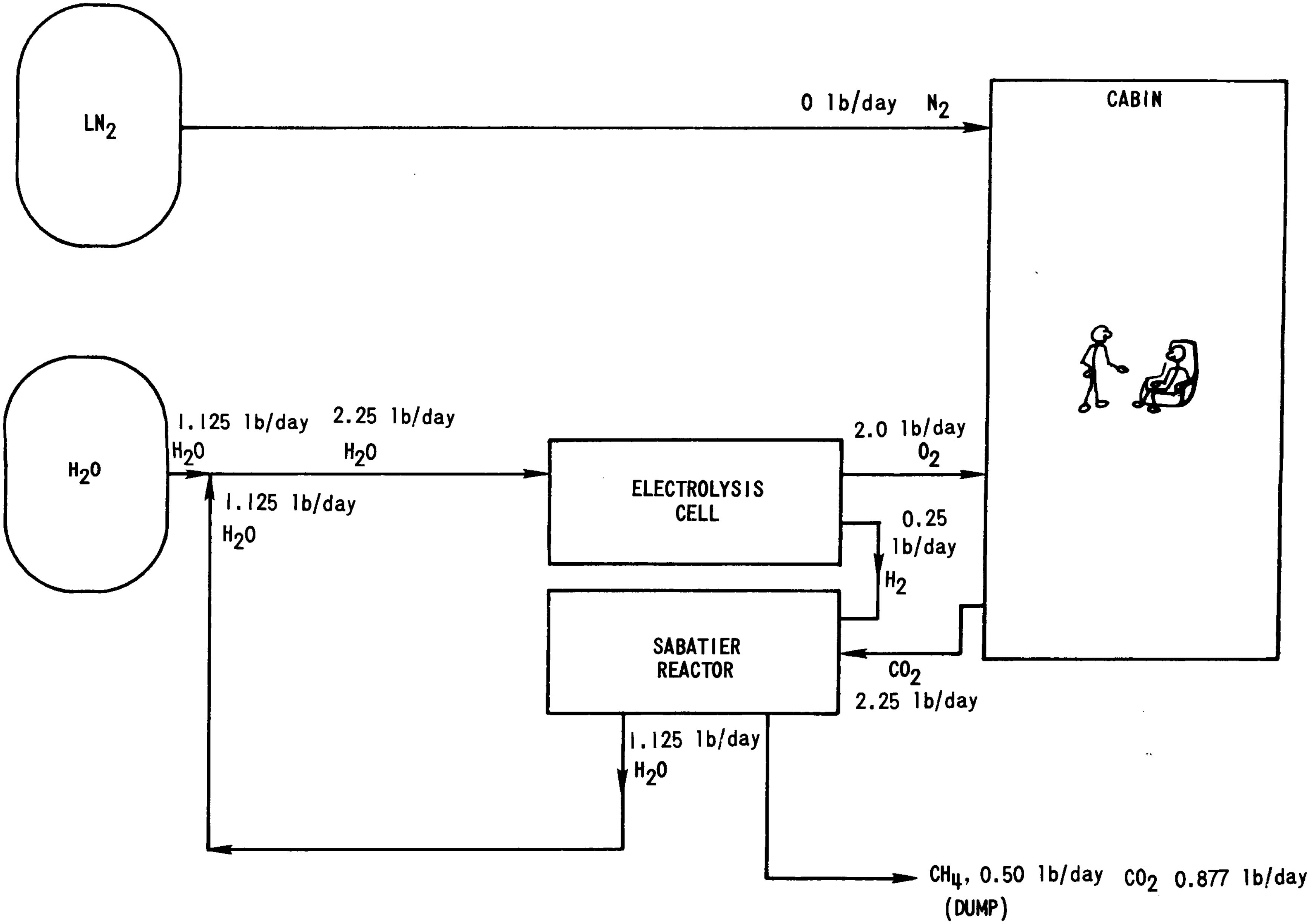

FIGURE 1a SABATIER REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR ZERO LOSSES _ ONE MAN

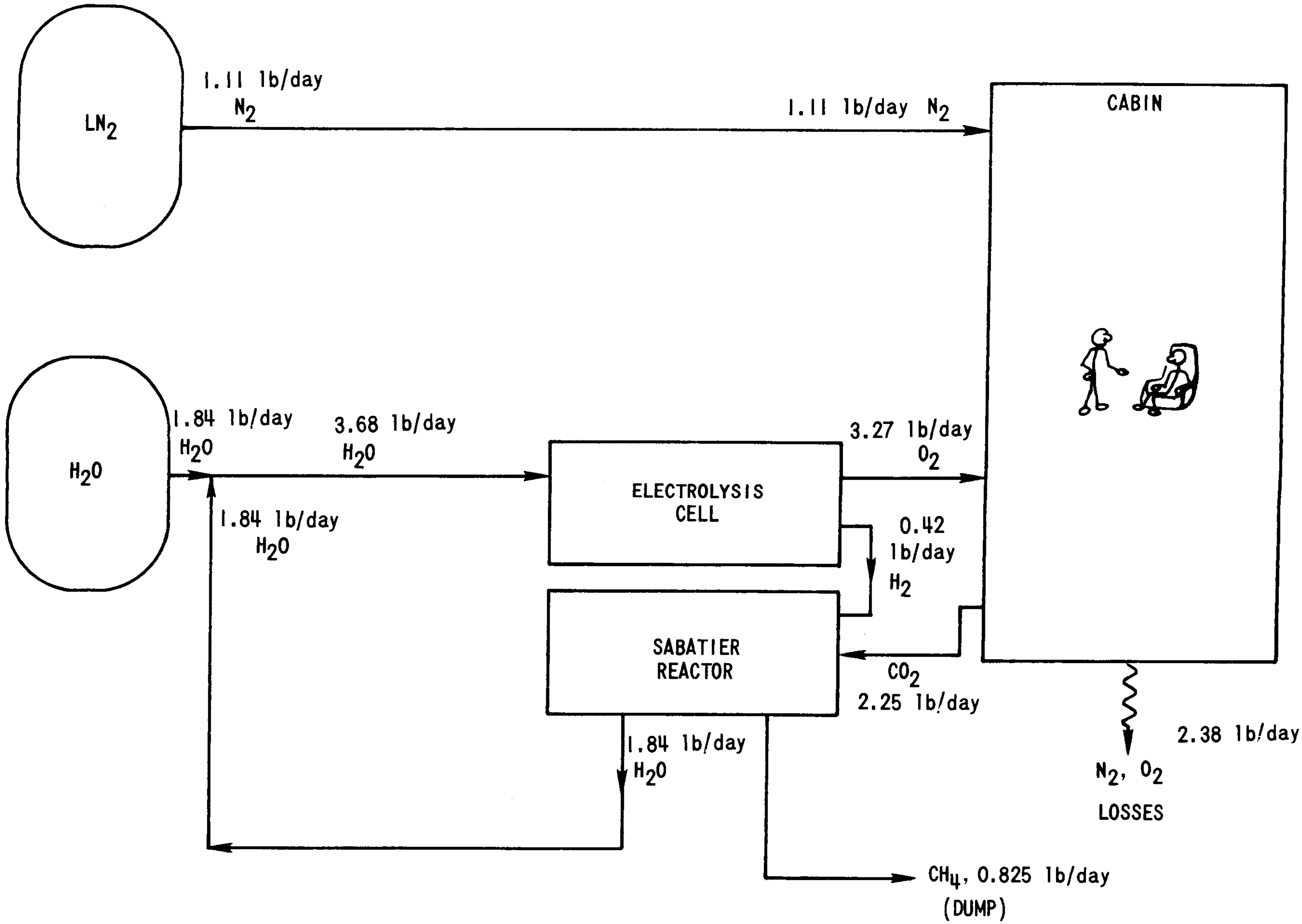

FIGURE 1b SABATIER REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR 2.38 lb/day LOSSES - ONE MAN

Appendix (continued)

- A Sabatier reactor which reacts the CO_2 with H_2 producing H_2O and CH_4.
- An electrolysis cell which electrolyzes the H_2O from the Sabatier reactor and releases O_2 to the cabin and H_2 back to the Sabatier reactor.
- Water storage system to store the water needed.
- Cryogenic LN_2 tank.

The CO_2 removal system currently at the highest stage of development is the Molecular Sieve. It employs a bed of Zeolite to absorb the CO_2 from the cabin atmosphere. The Zeolite is then desorbed by heating and pumping out the CO_2.

The CO_2 is mixed with H_2 and fed into the Sabatier reactor. The Sabatier reactor is a bed of catalyst at 500°F-700°F. The reactor usually incorporates a counterflow heat exchanger to act as an economizer to heat the incoming flow and cool the outflow. With efficient catalysts, a suitable temperature gradient in the reactor, and a low volume flow rate the conversion efficiency of the reactor can be well over 99%. (99.8% after 800 hours of operation at 210°C--Reference 4.) The reaction is exothermic so that no external energy need be supplied. The process is continuous.

The outflow of the reactor is a mixture of H_2O, CH_4 and any unreacted H_2 and CO_2. The outflow is then cooled in a condensing heat exchanger to remove all the H_2O. The remaining CH_4 is dumped overboard. The H_2O is then pumped to the water electrolysis cell directly or into the water management system which then supplies the electrolysis cell.

The water electrolysis cell must be designed for zero-g. The requirement for zero-g operation has led to the concept of a porous matrix or membrane which just touches the electrode (which is usually a catalytic screen) and the H_2 and O_2 generated at the fluid-electrode interface is separated from the liquid by surface tension. There have been problems in the past in the durability and reliability of these devices but a second generation of electrolysis cells with greater reliability and maintainability is coming into use (References 5, 6).

Appendix (continued)

6.1 System 1 Weight and Performance

The metabolic requirement for O_2 for a crew of N is 2.0N lb/day. In the 7 psi 50:50 O_2:N_2 atmosphere the loss overboard of 1 lb of cabin atmosphere results in the loss of 0.534 lb of O_2 and 0.466 lbs of N_2. The total requirements in the cabin are:

- N_2 requirement - 0.466 L
- O_2 requirement - 0.534 L + 2N

where L is the loss rate of cabin atmosphere from all causes and N is the number of crewmen. The weight of the Sabatier reactor, depending upon the type of thermal control used, varies from (5 + 1N) lb to (20 + 4N) (References 7, 8).

The weight of electrolysis cells with redundant capacity (for reliability) varies from 15 (N + 0.26L) to 50 (N + 0.26L) (References 5, 7). The electrolysis cell uses the most power in the system. Although the theoretical power is ~160 (N + 0.26L) watts, real electrolysis cell efficiencies have been rather lower resulting in power requirements of ~250 (N + 0.26L) watts.

The consumables, however, make up the greatest part of the weight of the system and they are, therefore, the most significant weight.

The combined reaction of electrolysis of the stored water and the Sabatier reactor is:

$$2H_2O + CO_2 \rightarrow CH_4 + 2O_2$$

Reduction of all the CO_2 will thus result in more than the metabolic requirement for O_2. Only enough CO_2 need be reduced to accommodate the O_2 need.

Appendix (continued)

If only enough CO_2 is reduced to meet the metabolic and loss requirement of 0.534 L + 2N. The total water requirement is then 1.125N + 0.300L. The LN_2 requirement is 0.446 L. This requirement is correct until all the CO_2 is reduced in the Sabatier reactor. The equation for the water-Sabatier reactor-electrolysis cell tells us that for every pound of oxygen thus produced 0.689 lb of CO_2 must be reduced. Since the crew only produces 2.25 N pounds of CO_2 per day these equations hold only as long as $(2N + 0.534L)\,0.689 < 2.25N$ or as long as

$$\frac{L}{N} < 2.38$$

If the loss rate per man $(\frac{L}{N})$ is greater than 2.38 lb/day, the extra O_2 requirement is being met at a water cost of

$$\frac{9}{8}\,(0.534L) \text{ or } 0.60L \text{ lb/day,}$$

so that the H_2O requirement equation can be defined for all loss rate as

$$0 < \frac{L}{N} < 2.38 \qquad H_2O \text{ req} - 1.125N + 0.300L$$

$$2.38 < \frac{L}{N} \qquad H_2O \text{ req} - 0.411N + 0.600L$$

The daily H_2O requirement can be partially met by the metabolic excess H_2O which could be recovered from the urine water and atmospheric condensate if the water management system were near 100% efficient. If the fecal water (0.25 lb/man day) is discarded there is still about 0.5 lb/man day available from urine and atmospheric condensate water. This is because food is composed of a mixture of carbohydrates and fats and protein. The carbohydrate is in general:

$$C_m\,(H_2O)_n$$

the fat:

$$(CH_2)_n$$

and the protein:

$$C_nH_mN_o.$$

Appendix (continued)

The metabolic processes are chiefly oxidation so that in effect:

$$O_2 + (\text{Food}) \longrightarrow CO_2 + H_2O + \text{Nitrogenous waste.}$$

The total water requirement does not therefore have to be met from stores. The water recovered from the water management system will be independent of the O_2 recovery system and can be subtracted from whatever requirement for stored water there is. The N_2 requirement of 0.466L is met from cryogenic storage of liquid nitrogen.

7.0 SYSTEM 2 DESCRIPTION (SABATIER/NH_3/H_2O)

The components of this system are represented in schematic form in Figure 2. The principal difference in the two systems is the source of N_2. The N_2 source is NH_3 which is dissociated and then separated into $H_2 + N_2$. The H_2 goes to the Sabatier reactor and the N_2 supplies the cabin N_2 requirement.

7.1 NH_3 Toxicity

NH_3 is a toxic gas whose level of obvious detectability is somewhat below its industrial threshold limit value (TLV). In a spacecraft life support system simulator test levels of 17 ppm (parts per million) were readily detected as smarting eyes and burning throats (Reference 5), as compared to a TLV of 50 ppm.

NH_3 is produced by normal body metabolism, chiefly as free NH_3 in urine. Water recovery systems which recover urine water must be able to accommodate >2 gms/man day of NH_3. Additional sources such as bacteriological breakdown of urea in perspiration generate as much as 1 gm/man day.

There is at present, some disagreement as to the efficacy of catalytic oxidizers in eliminating NH_3 from the cabin atmosphere, however, the combination of pre and post

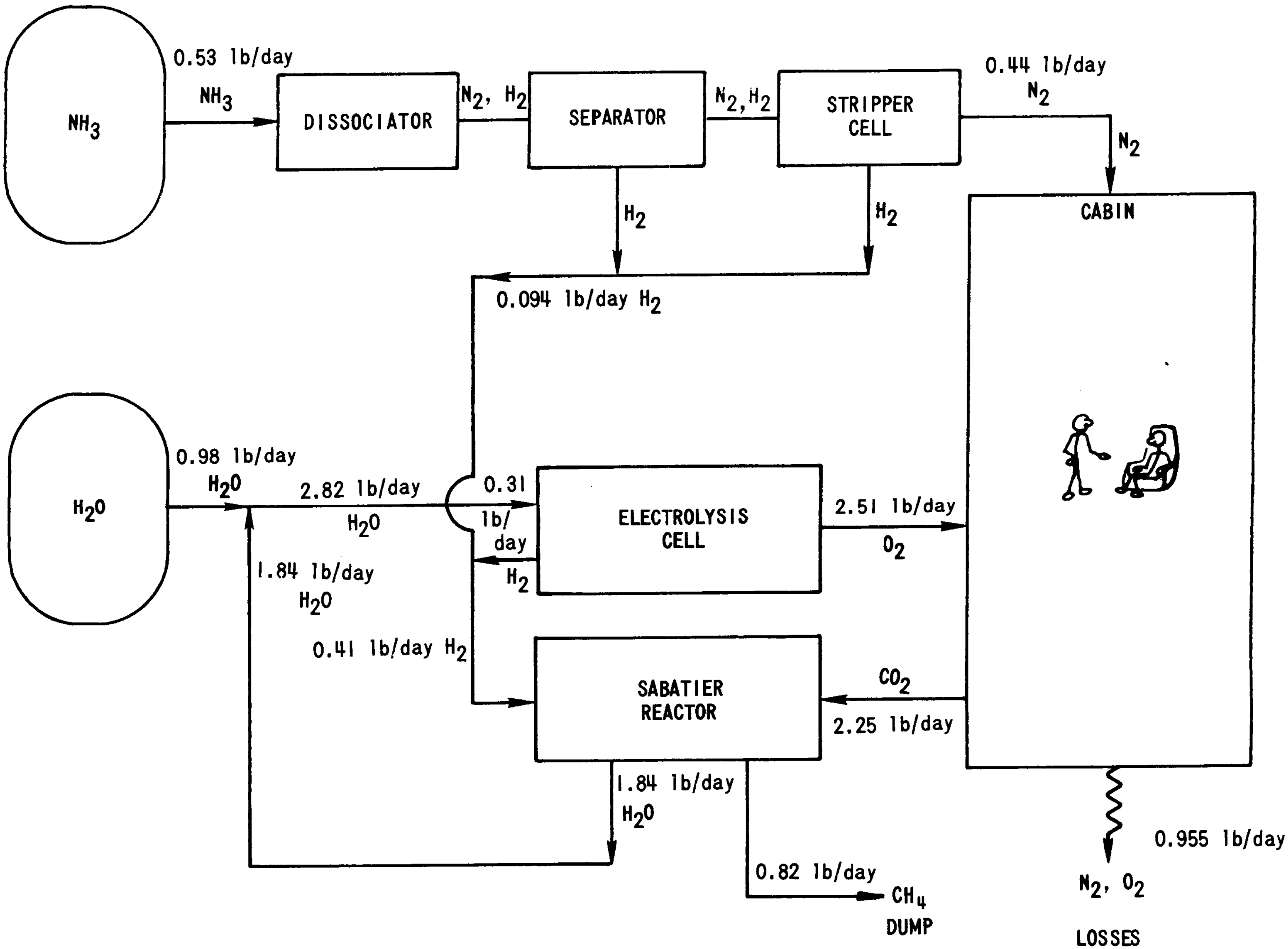

FIGURE 2 SABATIER SYSTEM WITH H_2O/NH_3 STORAGE LOSS RATE OF 0.955 lb/day FOR ONE MAN

sorbant beds used in conjunction with a catalytic oxidizer has eliminated it in the past. The easy detectability of NH_3 helps counteract the danger of poisoning which is present in possible system malfunction.

7.2 NH_3 Dissociator

The dissociator is a high temperature catalytic reactor in which the reaction

$$\frac{1410\text{BTU}}{\text{lb } N_2} + 2NH_3 \xrightarrow[\text{catalyst}]{1400\text{-}1800°F} N_2 + 3H_2$$

takes place. NH_3 dissociators have been used as H_2 sources in the chemical industry for more than 10 years. An existing dissociator capable of producing 0.745 lb/hr of H_2 (and 3.48 lb/hr of N_2) is a coil of 7 turns of one-inch Inconel 600 tube (0.065 wall thickness), wound around a 3.375 inch mandrel, filled with a nickel based catalyst (Reference 9). A dissociator can incorporate an isotope heat source to provide the 1410 BTU/lb of N_2 required. On a 24 hour basis this implies requirement for 8.05L watts of heat from the isotope. The dissociator would incorporate a counterflow heat exchanger to heat the NH_3 to 1800°F and cool the H_2, N_2 mixture leaving the dissociator. The total weight of the dissociator including the heat source, dissociator, and counterflow heat exchanger can be assumed comparable to a radioisotope heated catalytic burner of the same thermal power (Reference 11). The weight is estimated at 2L lbs.

7.3 N_2-H_2 Separator

The stream of N_2 and H_2 is cooled to about 800°F and passed into the separator. The separator as used in the chemical industry and laboratories is a set of PdAg alloy tubes at 800°F across which the H_2 diffuses. At active sites on the surface of the palladium the diatomic H_2 molecule splits into atomic hydrogen which reacts with the palladium forming

Appendix (continued)

PdH_x, a non-stoichiometric hydride. At high temperature the palladium becomes saturated with hydrogen. If there is a difference in the hydrogen partial pressure across a thin sheet of the material, the sheet will act as a semi-permeable membrane allowing only the hydrogen to pass through. In laboratory and industrial diffusers one square foot of material 3 mils thick will allow 0.18 lb/hr of H_2 to diffuse through when driven by a potential difference of 180 psi (at 380°C). Higher temperature will increase the permeability and in industrial units the temperature is usually set at 430°C.

Both the hydrogen diffuser cell and the dissociator are used as a single package in industry and laboratories as a source of high purity H_2 from NH_3. The industrial units are static long life devices. The life (MTBF) of industrial units under daily thermal cycling, no maintenance conditions is 3-4 years. In a spacecraft the unit would operate at constant conditions and essentially have the life characteristics of a heat exchanger. The separator could be significantly derated from its industrial form and achieve higher efficiency (% separation of H_2) with a weight of 1.5L lbs. The separator will only work if there is a pressure differential across the membrane. There is a limit to its effectiveness. Commercial units generally recover only 70% of the H_2. By making the diffuser longer, it can recover 95% of the H_2 from a 150 psi stream down to a 5 psi output.

The remaining 5% of the H_2 must be either reacted in the atmosphere systems catalytic burner or removed in a "stripper" cell (Reference 4).

The stripper cell is an electolytic H_2 pump. It is capable of removing the residual H_2 from the N_2 stream that the diffuser misses. It is 2 hollow Pd-25 Ag electrodes through which H_2 is diffused to a KOH solution. Electrolysis cells of this construction have run for more than 1.5 years without difficulties at Batelle (References 4, 6). The power consumption of the cell assuming a 0.4V. voltage drop across the cell is 206 w./lb H_2 per day or 2.08L watts if the diffuser works at a nominal 90% effectiveness. If the diffuser doesn't work at all, a redundant mode would have the stripper cell do

Appendix (continued)

all the separation at a power requirement of 20.8L watts. The stripper cell weight is estimated to be 0.344 lb/watt or 0.7L lbs with the diffuser operating at 0.9 nominal effectiveness. The NH_3 dissociator-diffuser-stripper system will therefore weigh about 4.2L lbs plus about 1 lb for controls. Adding 1 lb for pumps and valves and 1 lb for lines gives a total of (5.2L + 3) lbs. The Sabatier reactor and the electrolysis cell weigh the same as they did in System 1 since they are the same system.

As in the Sabatier H_2O/LN_2 system, the most important weights are the consumable items. In the H_2O/NH_3 system the following processes take place.

7.4 System 2 Weight and Performance

The leakage nitrogen requirement is met by dissociation of NH_3. The H_2 from the reaction goes to the Sabatier reactor electrolysis cell system. The reactions are

$$2NH_3 \longrightarrow N_2 + 3H_2$$

$$4H_2 + CO_2 \longrightarrow 2H_2O + CH_4$$

$$2H_2O \longrightarrow 2H_2 + O_2$$

or altogether

$$3CO_2 + 4NH_3 \longrightarrow 2N_2 + 3O_2 + 3CH_4 \, .$$

The H_2 from the NH_3 is sufficient to reduce enough CO_2 to produce 3 moles of O_2 to every 2 moles of N_2 needed. The requirement for H_2O in the Sabatier system is then limited to the amount of O_2 needed.

Appendix (continued)

The N_2 requirement of 0.466L lb is met by the dissociation of $\frac{17}{14}$ (0.455L) or 0.566L of NH_3 with the H_2 going to the Sabatier reactor-electrolysis cell combination and resulting in the production of 0.800L of O_2 and reduction of 1.1L of CO_2. The remaining O_2 requirement is met by supplying the Sabatier reactor-electrolysis cell with H_2O from storage. The remaining O_2 requirement is (2N+0.53L) lb-0.800L lb or (2N-0.266L) lb. The H_2O taken from storage to meet this requirement is $\frac{18}{32}$ (2N-0.266L) lb or (1.125N-.1496L) lb. This H_2O will reduce (1.375N-0.183L) lb of CO_2. As there is only 2.25N lb of CO_2 produced by the crew daily, this ecology will only hold when there is CO_2 remaining or when (1.375N-0.183L) + 1.1L) $<$ (2.25N) or when L $<$ 0.955N. For higher leak rates, the O_2,N_2 requirements are met by electrolyzing H_2O and dissociating more NH_3 and disposing of the excess H_2.

8.0 SYSTEM 3 DESCRIPTION (BOSCH/LN_2/H_2O)

The Bosch reactor system is presented in schematic form in Figure 3. The reaction, because it produces solid carbon and H_2O vapor takes place in a closed circuit, i.e., only H_2, CO_2 go in and H_2O liquid comes out. Nothing is dumped. In order to prevent the carbon from clogging the reactor, a gas pump operating at high temperature recycles the reaction products around a circuit. In the circuit is some type of carbon removal system. Presently experimentation is going on with removable cartridges in which the carbon accumulates. There have been problems with this process. The reaction

$$2H_2 + CO_2 \rightarrow 2H_2O + C$$

procedes catalytically not only on the iron catalyst of the catalyst bed, but in the flow passages of the heat exchanger, in the pumps--everywhere there is iron or even on the carbon already distributed in the system. Carbon clogging has been the major hurdle in Bosch system design. Efforts at Langley are currently aimed towards solution of this problem.

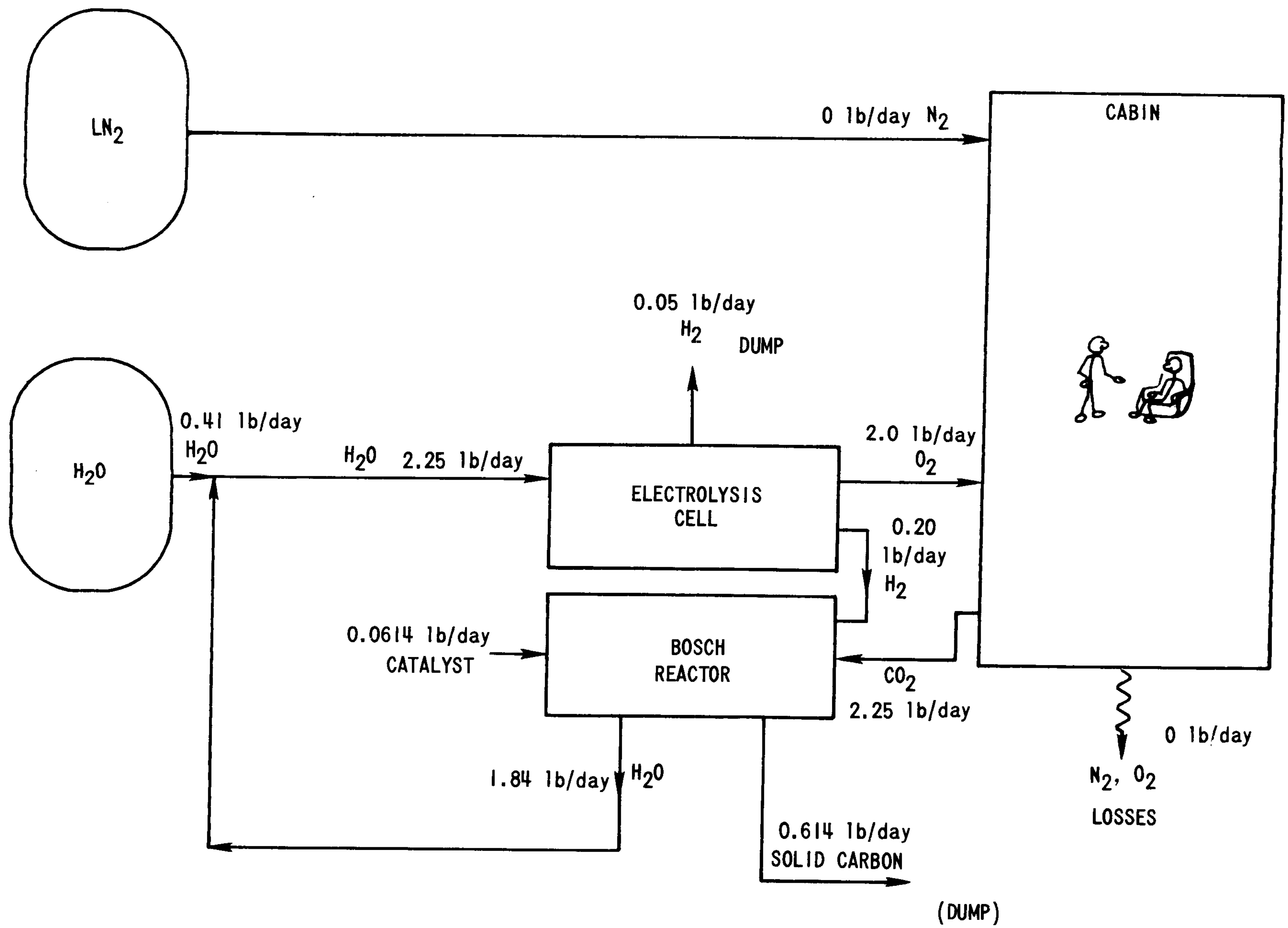

FIGURE 3a BOSCH REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR ZERO LOSS RATE - ONE MAN

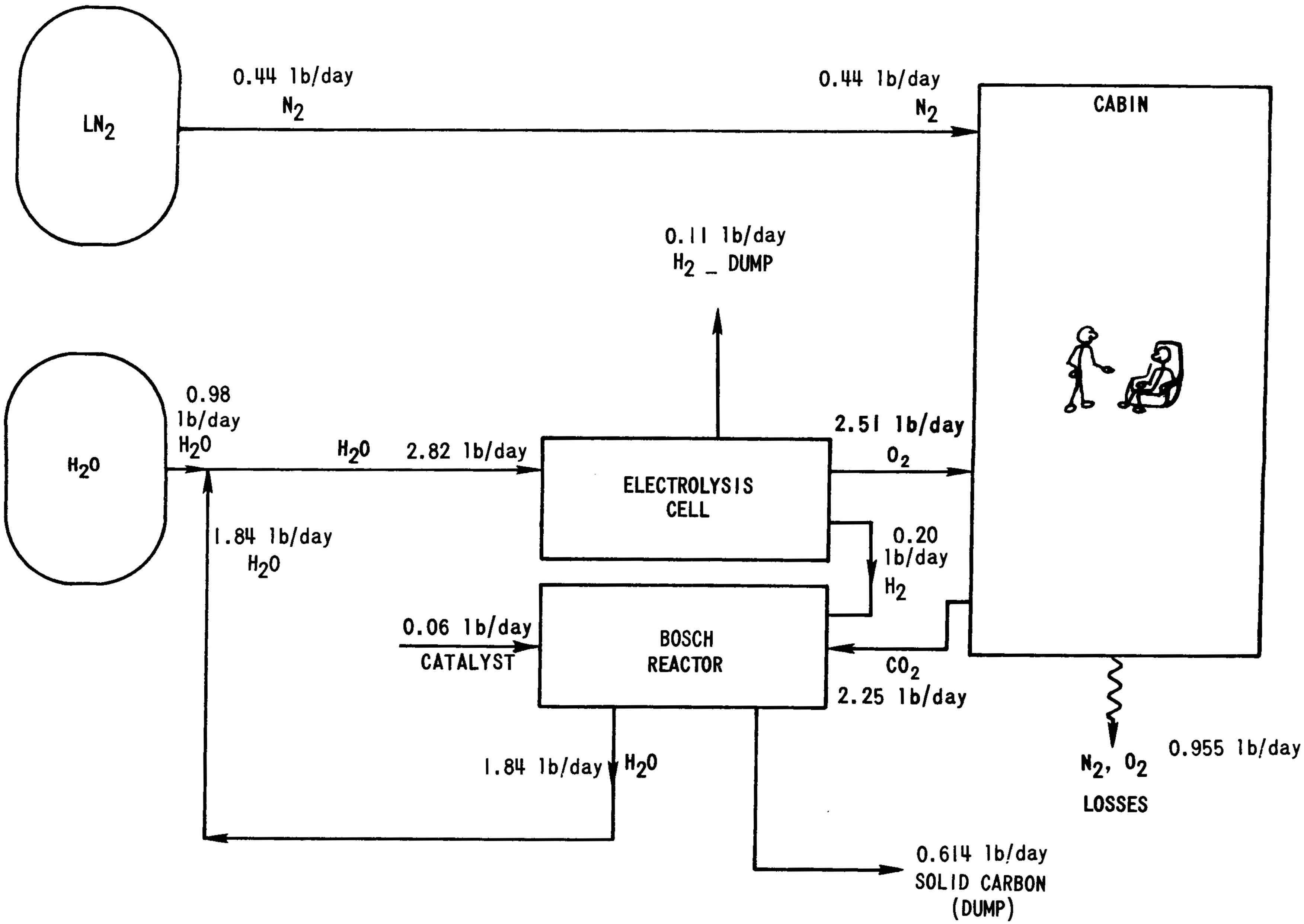

FIGURE 3b BOSCH REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR 0.955 lb/day LOSS RATE _ ONE MAN

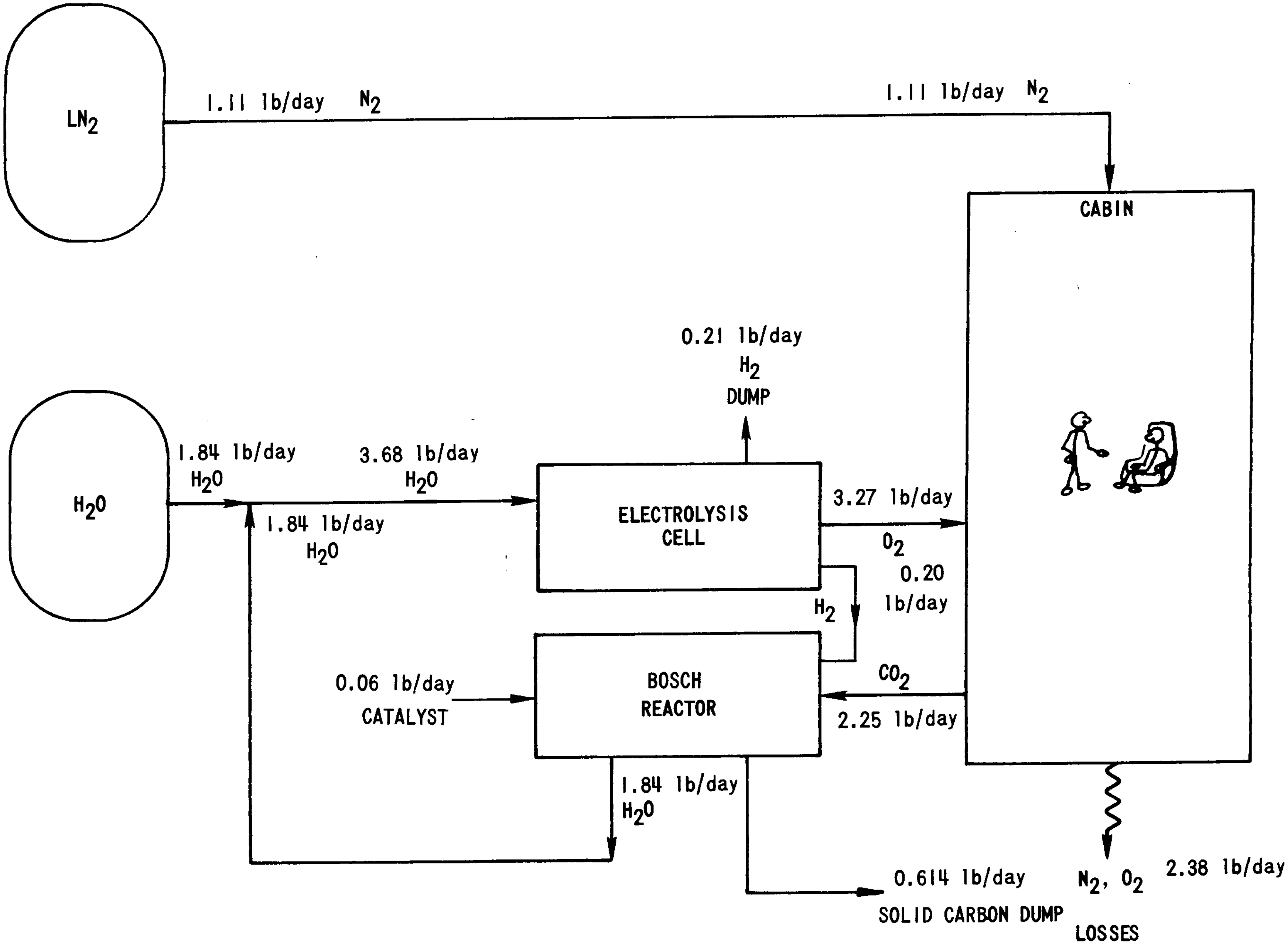

FIGURE 3c BOSCH REACTOR SYSTEM WITH H_2O/LN_2 STORAGE FOR LOSS RATE = 2.38 lb/day - ONE MAN

Work for the Air Force at TRW (Reference 10) using iron plates as a catalyst and scraping off the "carbon" and separating it from the gas stream in a centrifugal cyclone separator has produced successful short time operation of the Bosch process. It has revealed that the carbon also contains iron from the catalyst (8-20%). The use of the Bosch would entail either an initial charge of catalyst adequate for the entire mission or a set of catalyst cartridges to be replaced as the catalyst became consumed. A weight of 10% of the replaceable "C" cartridges is envisioned as adequate. The Bosch reaction, although it is exothermic does not release enough energy to heat the reactant up to the reaction temperature with a counterflow heat exchanger for the products. It needs an external heat source. It also needs a high temperature pump to pump the gases in the reactor around the catalyst, through the condensing heat exchanger, through the carbon separator, and back to the reactor.

The heating and pumping power requirement is estimated to be 70N watts. An undesirable feature of the Bosch reactor is that the recycle gas stream contains CO in high concentration so that utmost care must be taken to avoid leakage of CO to habitable spaces in the spacecraft. The closed circuit nature of the reactor means that it must be occasionally relieved of excess pressure caused by the small amount of nitrogen which may be fed into it as an impurity in the CO_2.

8.1 System 3 Weight and Performance

The consumable weights for the Bosch system, due to its closed H_2 cycle, are quite low. The complete reduction of all of the CO_2 gives an oxygen supply of (1.64N) lb with the consumption of only .0615N lb of catalyst. The rest of the oxygen consumed by the crew was transpired in the form of H_2O, and is recovered essentially by electrolysis of the excess humidity condensed from the atmosphere. The hydrogen from this electrolysis is discarded. The N_2 requirement of 0.466L is met from cryogenic LN_2 storage.

9.0 SYSTEM 4 DESCRIPTION (NO CO_2 REDUCTION LN_2/LO_2)

The simplest spacecraft ecology is one of dumping the CO_2 and taking O_2 and N_2 from storage. The requirement of (2N + 0.53L) lb/day O_2 and (0.466L) lb/day N_2 are met from cryogenic tanks of LO_2 and LN_2. It is shown in Figure 4.

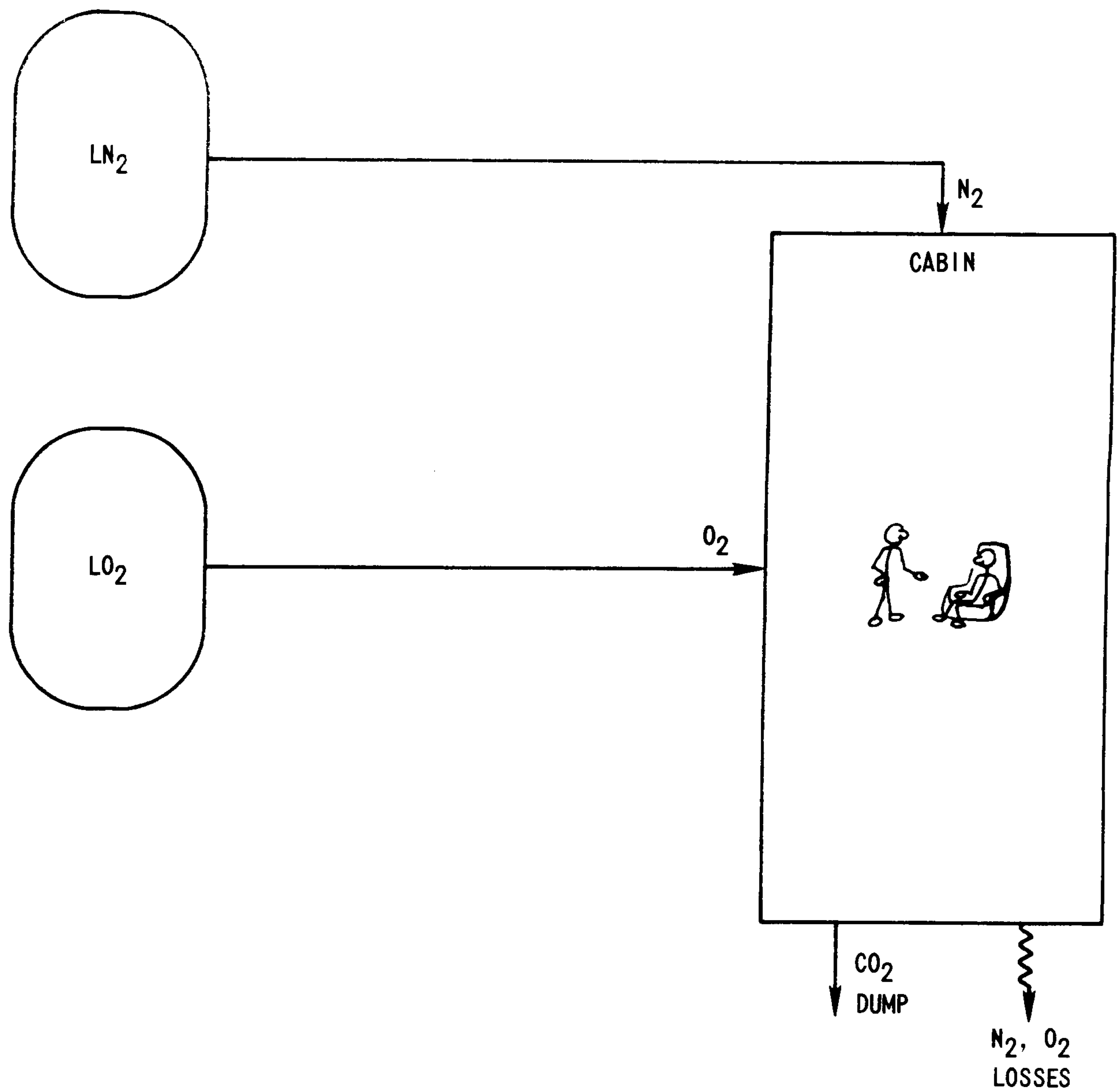

FIGURE 4. LO_2/LN_2 SYSTEM WITH CO_2 DUMP

RESULTS AND CONCLUSIONS

Figure 5 compares the daily requirements for each system for varying leak rates. The system power requirement for varying leak rates is shown in figure 6. The Bosch reactor system, because it reduces all the CO_2 at all leak rates, is the most economical system for low leak rates. The difference diminishes, however, with increasing leak rate and at the relatively low rates expected from advanced design, the consumption rates are comparable.

The total system weights are defined in Table 1, and shown in figure 7 for varying leak rates, for a two-year mission. The Sabatier reactor with NH_3, H_2O has approximately the same overall weight for leak rates in excess of 0.955 lb/man-day.

The performance of the Sabatier system can be increased by the addition of a methane-"cracker". Several approaches to this process are being looked into at present and, if successful, the Sabatier system can be improved to equal the performance of the Bosch system with fewer problems, as well as the off-design non-methane cracking mode being available as a backup. H_2O and NH_3 can be stored indefinitely because they don't boil off. A spacecraft can thus remain dormant for extended periods of time and not lose its atmospheric supply as shown in figure 8. An additional advantage of the uninsulated NH_3 and H_2O tankage is the fact that there is no weight penalty if the design dictates several small tanks instead of one longer one.

The Sabatier reactor system with NH_3/H_2O storage is very attractive for near term missions. The lack of developmental difficulties so far demonstrated by Sabatier reactor experience in manned, and unmanned life support simulators indicates that it is a real option for the '71-'75 time period. By 1975 the Bosch reactor may have been successfully operated or some system which combines a Sabatier reactor with a CH_4 dissociator to recover its H_2 will have been developed. Detailed analysis of the NH_3/H_2O atmospheric supply system is recommended. NASA should consider including the NH_3/H_2O cycle in a life support simulator test.

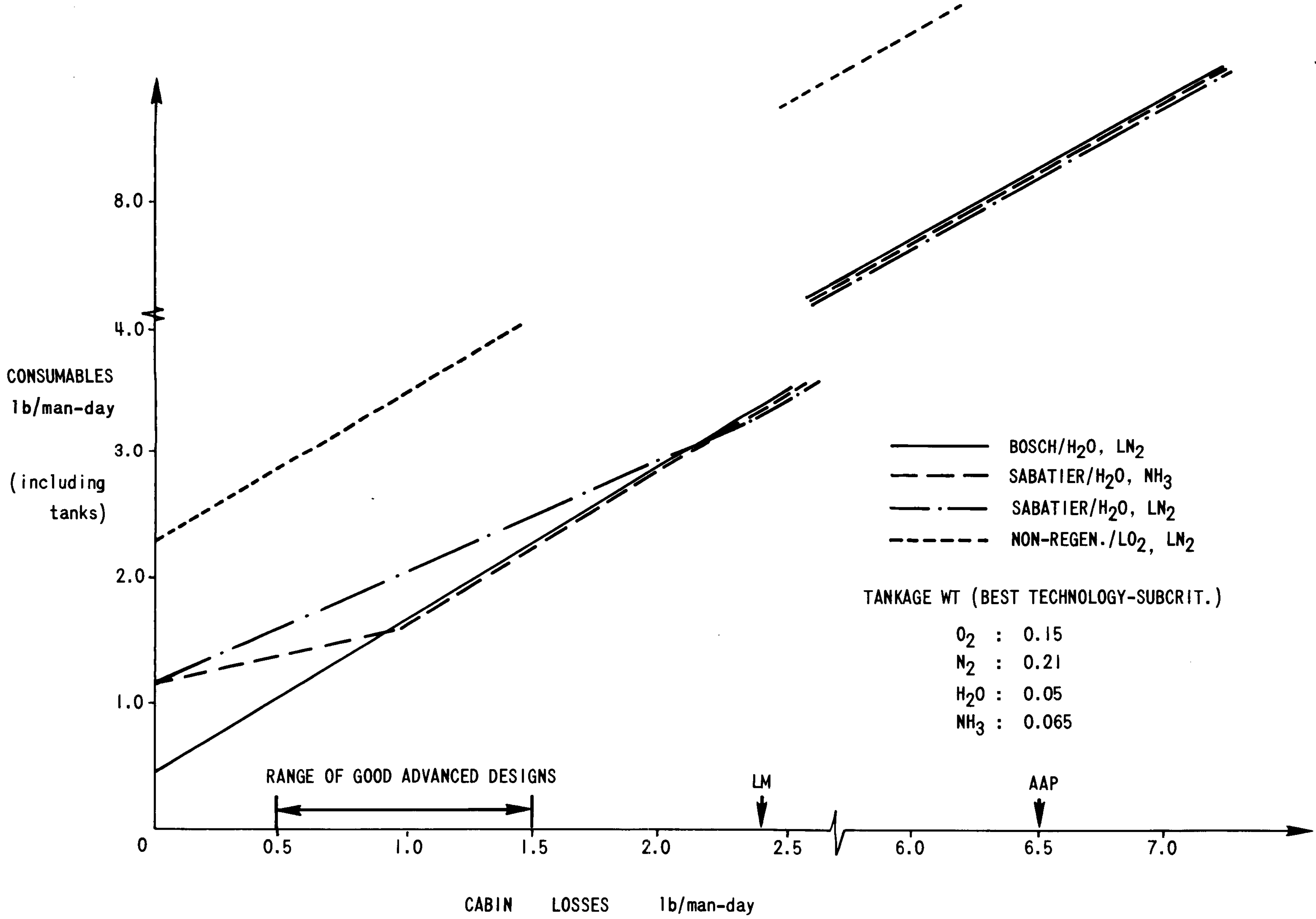

FIGURE 5 DAILY CONSUMABLES FOR ONE MAN VERSUS LOSS RATE

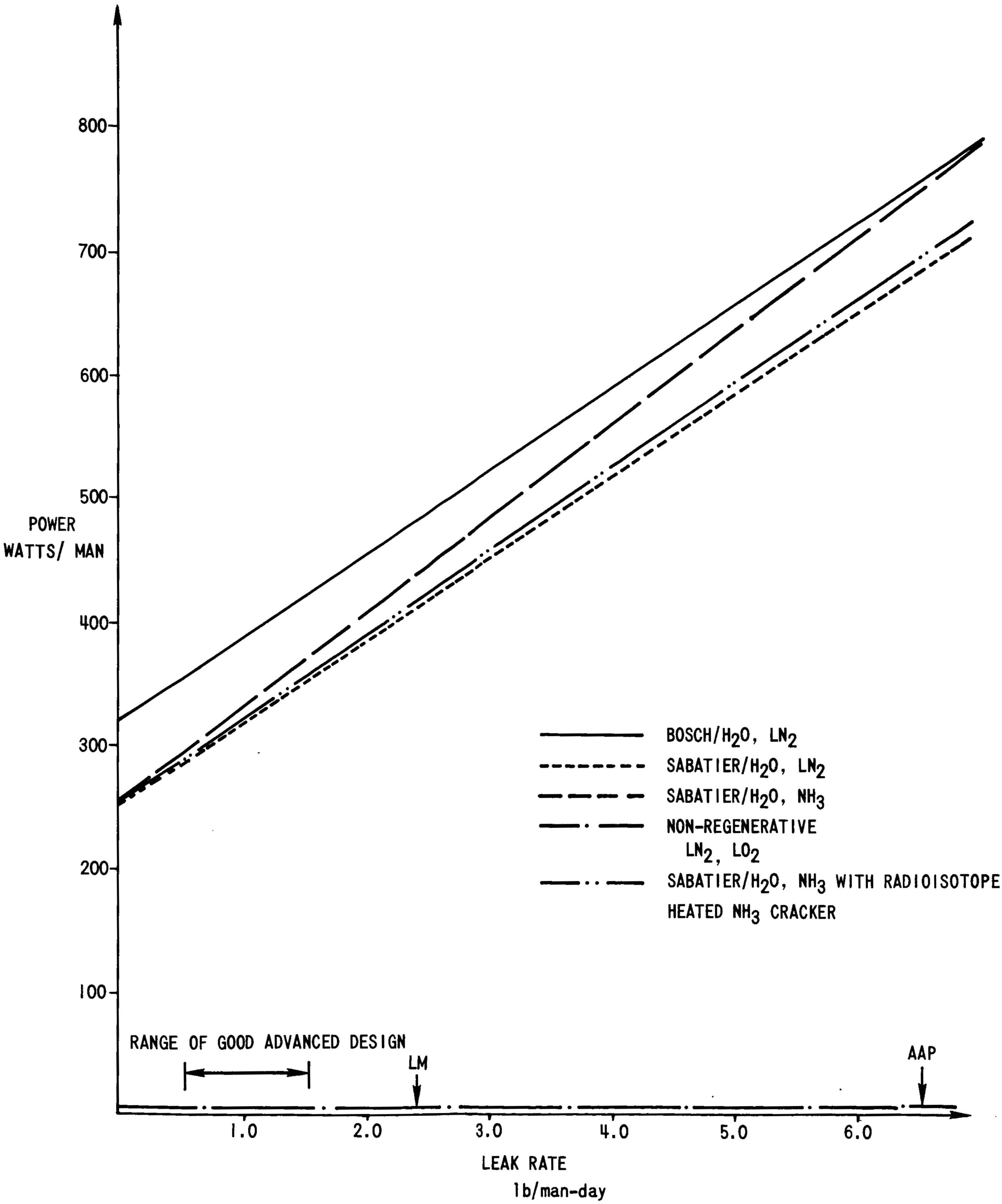

FIGURE 6 - POWER CONSUMPTION VERSUS LEAK RATE

TABLE 1

2 YEARS

SYSTEM	FIXED WEIGHT (lb)	POWER WATTS (continuous)	DAILY CONSUMABLES (lb)		TOTAL WT. (lb) 803 day (years + 10%)	TANKAGE FRACTION: H_2O = 0.05 NH_3 = 0.065 LN_2 = 0.21 LO_2 = 0.15	TOTAL WEIGHT PER MAN FOR 0.6 LB/MAN DAY LOSS 2 years
Sabatier CO_2 Red. W H_2O + LN_2 Storage	10+22N +5.3L	250N +67L	$L<2.38N$ H_2O: 1.125N+0.3L LN_2: 0.466L	$L>2.38N$ H_2O: 0.411N+o.6L LN_2: 0.466L	$L<2.38N$ 10+ 972N +712L	$L>2.38N$ 10+369N + 965L	1409
Sabatier CO_2 Red. W H_2O + NH_3 Storage	13+22N +10.5L	250N +77.1L	$L<0.955N$ H_2O: 1.125N-.15L NH_3: 0.566L	$L>0.955N$ H_2O: .410N+.6L NH_3: 0.566 L	$L<0.955N$ 13 + 972N + 368L	$L>0.955N$ 13+369N +1001L	1206
Bosch CO_2 Red. W H_2O LN_2 Storage	35N+20 +5.3L	320N + 67L	H_2O: 0.41N+0.60L N_2: 0.466L Catalyst Cartridges: 0.0615N		431N +965L +20		1030
CO_2 dump LN_2 LO_2 Storage			LO_2 2N+0.534 L LN_2 0.466 L		1850N +948L		2419

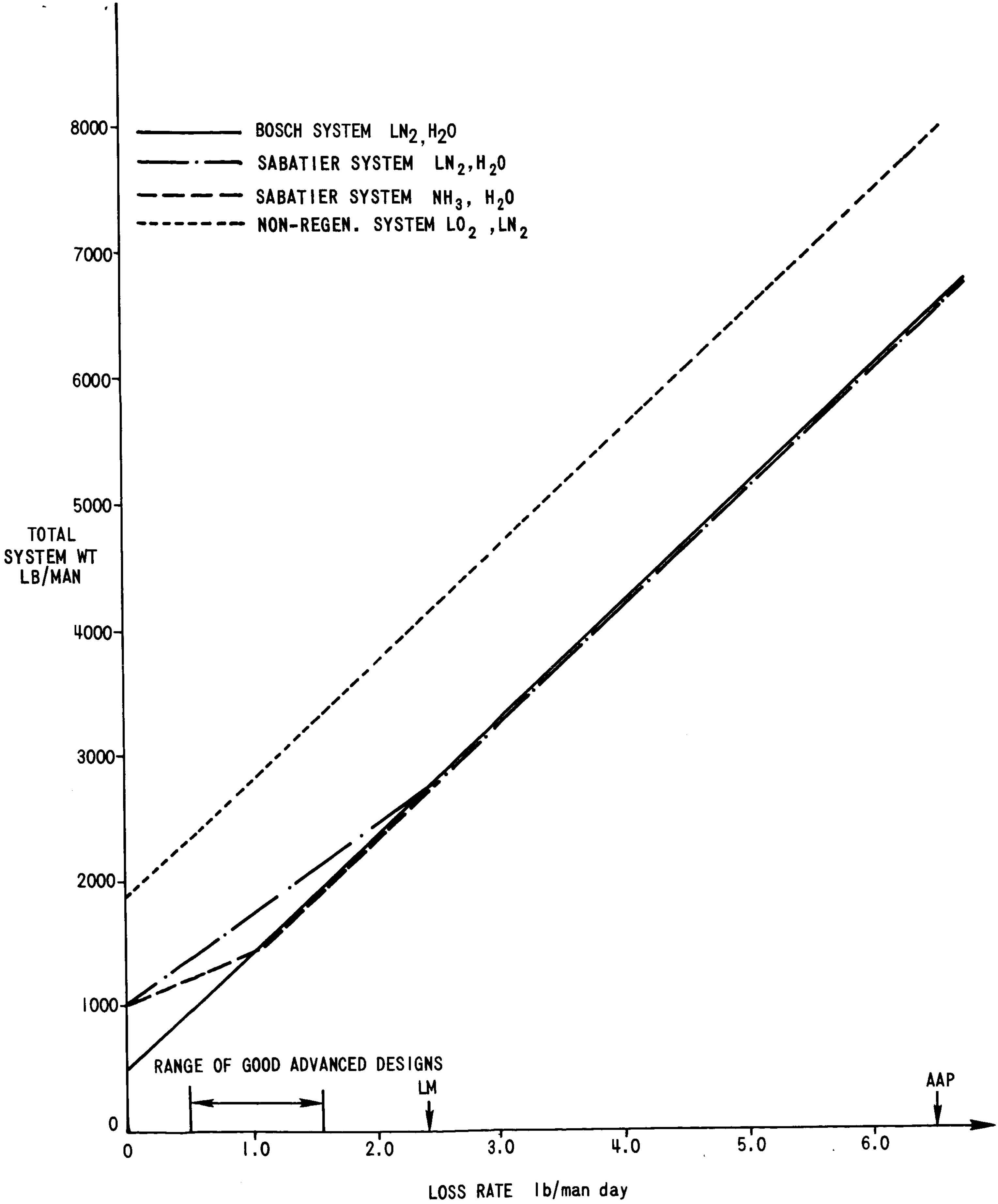

FIGURE 7 SYSTEM WEIGHT FOR ONE MAN VERSUS LEAKAGE RATE FOR 803 DAYS (2 years + 10%)

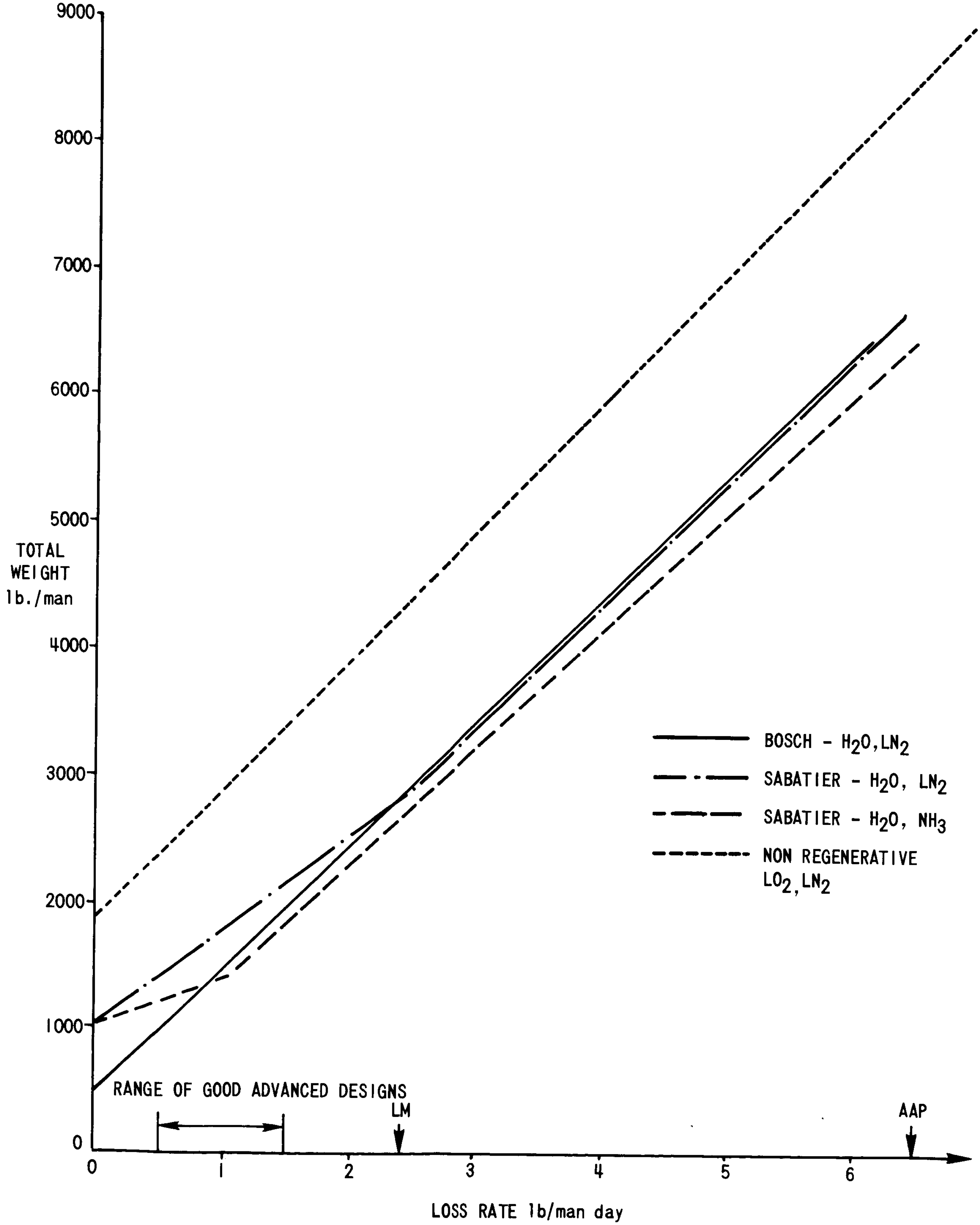

FIGURE 8 TOTAL WEIGHT FOR 1 MAN FOR 803 DAYS + 90 DAY ORBIT STORAGE

REFERENCES

1. Macchia D.: Visit to Integrated Life Support System Facility at LRC - Trip Report June 26, 1967.

2. Gorman, R., Macchia, D.: Trip Report - Visit to Aeronutronic and LMSC, November 29, 1967.

3. Gorman, R.: Trip Report - Douglas Technical Debriefing for 60 day Manned Regenerative Life Support System Simulator Test, May 13, 1968.

4. Investigation of an Integrated CO_2 Reduction and H_2O Electrolysis System J. E. Clifford, et al Batelle Memorial Inst. AD 655 937.

5. Lockheed "Two-Gas Regenerative Life Support System" Briefing January 19, 1968.

6. Water Electrolysis Cells Using Hydrogen Diffusion Electrodes. Edwin C. Kolic, et al Batelle Memorial Inst. Nov. 1967 AD 664 361.

7. Integrated Manned Interplanetary Spacecraft Concept Definitive Vol. VI Cost-Effect Subsystem Selection and Evolutionary Development Boeing Co. NASA CR-66564.

8. Parameter Study of Manned Life Support Systems Second Quarterly Briefing, February 15, 1968.

9. A Hydrogen Generator, Allis Chalmers Res. Division, Raymond L. Costa, AD 642 140.

10. Water and Carbon Removal from Carbon Dioxide Reduction Systems, Andrew D. Babinsky, Stephen J. Derezinski, TRW.

11. Study and Preliminary Design of an Isotope Heated Catalytic Oxidizer System NASA CR 66346, T. M. Olcott, Biotechnology Organization, Lockheed Missiles and Space Co. Sunnyvale.

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